SNAP FAQ

March 24, 2000

Contents

1 Science **3**

1.1 How do $z \geq 1.2$ supernovae help in measuring the cosmological parameters? . . . 3

1.2 What is the experimental evidence for an accelerating universe and the existence of dark energy? . . . 3

1.3 What contributions can SNAP make to the field of high-energy physics? 3

1.4 It seems that SNAP will be an excellent tool for a wealth of astrophysical studies; what non-supernova science do you plan for SNAP? . . . 4

1.5 What special contribution will SNAP make to field of cosmology in the next 10 years? How will it complement the cosmological parameters and dark energy properties measured by other experiments, such as Planck, SDSS, cluster abundance experiments etc.? . . . 4

1.6 How is the current theoretical understanding of SNe Ia? . . . 5

2 Alternative and Complementary Missions **6**

2.1 What are the problems with a ground-based search and/or follow-up with resources that will be available in the next decade? . . . 6

2.2 What problems are there in searching with other space telescopes that will be available in the next decade? . . . 6

2.3 What are the problems with doing follow-up with other space telescopes that will be available in the next decade? . . . 6

2.4 Why will a follow-up satellite with a smaller field of view (FOV) coordinated with ground discovery not work? . . . 7

3 Systematics **7**

3.1 What are the independent checks on gray dust? . . . 7

3.2 How will gray dust be detected and characterized? . . . 7

3.2.1 and what if there is an important mechanism for dust creation or destruction at $z > 0.5$ that cannot be reconstructed from the dust at $z < 0.5$? . . . 8

3.3 How degenerate are the combined evolutionary effects? . . . 8

3.4 How degenerate are gray dust and evolutionary effects? . . . 8

3.5 Is there evidence for SN Ia evolution? . . . 8

4 Data **9**
4.1 What are your target peak-magnitude measurement uncertainties? . . 9
4.2 How do you flatfield in space? 9
4.3 What will the cosmic-ray rate be in your high-Earth orbit? 9

5 Budget **10**
5.1 Why does SNAP, with its 1 billion pixels, cost less than NGST with 80 million pixels? 10
5.2 What is the main driver of the study/engineering budget? 10

6 Risk **10**
6.1 How will the risks of this space mission be managed? 10

1 Science

1.1 How do $z \geq 1.2$ supernovae help in measuring the cosmological parameters?

It is important to obtain supernovae at a wide range of redshifts. An arbitrarily large number of supernovae at fixed redshifts will not continue to improve the uncertainties in the cosmological parameters because systematic errors will dominate. Only by moving to new redshifts, where the luminosity distance depends differently on Ω_M and Ω_Λ, can more supernovae be used to improve the determination of these parameters. Simulations show that with SNAP's baseline mission, supernovae should be observed out to $z = 1.7$ to optimize its parameter determination capabilities.

It is essential that we probe the redshift region in which normal matter dominated over the dark energy so we can validate our cosmological determinations. The supernovae at $z > 1.2$ will provide a consistency check since potential systematic effects, such as gray dust and evolution, are not expected to mimic the Hubble diagram of pure cosmological models for the full $0.3 < z < 1.7$ redshift range.

1.2 What is the experimental evidence for an accelerating universe and the existence of dark energy?

Three independent cosmological probes provide evidence that the universe is accelerating; SNe Ia, the Cosmic Microwave Background, and galaxy clusters. The CMB results indicate a flat universe $\Omega_M + \Omega_\Lambda \sim 1$, mass density measurements from galaxy clusters point to $\Omega_M \sim 0.3$, and the supernova results approximately give $0.8\Omega_M - 0.6\Omega_\Lambda \approx -0.2$. *Two* of these results would need to be incorrect if the universe's expansion were not accelerating.

The SNAP set of supernovae, with its uniform distribution in a large range of redshift and extensive photometric and spectroscopic coverage is designed specifically to provide a dataset that is complete enough to be able to address and study alternative cosmological scenarios. If SNAP can invalidate the current results and replace them with more reliable measurements of the scale of the universe as a function of time, it will be as important as if it confirms them.

1.3 What contributions can SNAP make to the field of high-energy physics?

The dark energy, whatever its nature, is unexplained by particle physics. If what we know classically as Einstein's cosmological constant is the dark energy, theory will be forced to explain why its value is 10^{120} times smaller than the Planck scale (or 10^{51} times smaller than the supersymmetry breaking scale) and yet non-zero. Alternatively, the dark energy may be due to a scalar field, i.e. a heretofore unknown particle. SNAP's unique capabilities of probing the redshift region where the dark energy dominates will help identify the nature of the dark energy and the fundamental fields of particle physics.

Here are some comments about the dark energy from members of the high-energy physics community.

> "Basically, people don't have a clue as to how to solve this problem." – *J. Harvey*
>
> "Right now, not only for cosmology but for elementary particle theory, this is the bone in our throat." – *S. Weinberg*
>
> "… maybe the most fundamentally mysterious thing in all of basic science." – *F. Wilczek*
>
> "… would be Number 1 on my list of things to figure out." – *E. Witten*

1.4 It seems that SNAP will be an excellent tool for a wealth of astrophysical studies; what non-supernova science do you plan for SNAP?

There is a wealth of scientific uses for the wide-field deep images that will be obtained as part of the baseline supernova search program. Weak and strong gravitational lensing and Type II supernovae, for example, will provide cosmological measurements independent of the Type Ia data. And like the Hubble Deep Fields (but 7000 times larger), our images can be used in a wide array of cutting-edge astronomical research such as discovery of the first galaxies and quasars formed in the universe, galaxy evolution and clustering, searches for gamma ray burst counterparts, planets, black holes, and red dwarfs, etc. SNAP will uniquely provide valuable targets for NGST to follow-up.

A percentage of SNAP time will be allocated to non-supernova activities. Proposals for key survey projects will be solicited and heritage or key-project-class guest programs will be considered so that the scientific community will have the opportunity to benefit from the unique capabilities of SNAP.

We plan to make all data available to the community as part of an archival program.

1.5 What special contribution will SNAP make to field of cosmology in the next 10 years? How will it complement the cosmological parameters and dark energy properties measured by other experiments, such as Planck, SDSS, cluster abundance experiments etc.?

Even though the amount and quality of data coming from the cosmological probes in the next decade will be astounding, high-precision measurements of the parameters Ω_M, Ω_Λ and w will be possible only by combining different but complementary probes. SNAP will be the most accurate single probe of these parameters and is the only one that currently has quantitative bounds on its systematic uncertainties. It will provide a much-needed benchmark against which the results of other planned experiments can be compared.

CMB experiments MAP and Planck are generally considered the currently most powerful cosmological experiments. Dark energy affects the CMB in three ways: by contributing to the distance to the surface of last scattering, through the Integrated Sachs-Wolfe effect and through gravitational clustering. All three effects are small, and as a result CMB can measure Ω_M, Ω_Λ and w only to moderate accuracy (although it can measure certain linear combinations of them, such as $\Omega_M + \Omega_\Lambda$, very accurately). However, it has been shown that combining SN Ia measurements and CMB data can lead to improvement of up to a factor of 10 in the determination of Ω_M and Ω_Λ due to the breaking of parameter degeneracies – much more than the naively expected $\sqrt{2}$ improvement.

Galaxy surveys, such as SDSS, map the distribution of matter and measure Ω_M (as well as higher-order statistics of the large-scale structure), but do not shed much light on the properties of the dark energy. However, when combined with supernova and/or CMB data, galaxy surveys help break the parameter degeneracies and provide a better measurement of contents of the universe.

Weak gravitational lensing provides a very promising method based on weak distortions of distant objects due to large-scale structure. It turns out that for accurate parameter determination (in particular regarding Ω_M, $\Omega_{\mathrm{D.E.}}$ and w) weak lensing lacks precision because the power spectrum of the convergence from weak lensing is relatively structureless (unlike the power spectrum of the CMB), while it depends on about 8 parameters. However, when combined with other techniques, such as SN Ia or CMB, weak lensing can help pin down the cosmological parameters, for instance the neutrino mass. SNAP will be able to measure weak lensing with more sensitivity to smaller mass scales than other currently planned programs.

Classical number density vs. redshift (dN/dz) tests do probe the desired redshift interval and are in principle capable of tightly constraining the aforementioned parameters, as has been known for several decades. The most important among these tests are evolution of clusters of galaxies (with data either from X-ray surveys or from the proposed Sunyaev-Zeldovich survey), evolution of galaxy abundance, and gravitational lensing counts as a function of redshift. Unfortunately, in practice dN/dz tests are dependent on selection effects and the intrinsic abundance of the objects in question (galaxies, galaxy clusters, gravitational lenses etc.), whose theoretical values are model-dependent and have to take into account complicated physics of these objects, e.g. evolution, formation rate, and mergers of galaxies.

1.6 How is the current theoretical understanding of SNe Ia?

Theoretical modeling does in fact succeed in reproducing the empirical relations that we see in SNe Ia, with differences in light-curve shapes, peak magnitudes, and spectral features being attributed to differences in fused ^{56}Ni, opacities, etc. The current models are sufficient to satisfy our scientific needs and are used in our baseline studies; future improvements in the supernova theory should only improve the science that comes from SNAP.

2 Alternative and Complementary Missions

2.1 What are the problems with a ground-based search and/or follow-up with resources that will be available in the next decade?

The primary obstacle for ground-based observations is atmospheric OH emission, which not only contributes Poisson sky noise but also propagates flatfield errors. In space the "sky" is much darker and the required measurement aperture is much smaller. For 3-hour ground-based 8-m observations, these errors would prevent us from making very early discoveries (~ 2 days after explosion rest frame) beyond $z = 0.55$. Color measurements critical for extinction determination could not be made at the requisite 0.02 mag precision (which propagates to a ~ 0.1 mag uncertainty in the corrected magnitude) beyond $z = 0.75$. Even larger telescopes would provide only modest gains in signal to noise because the flatfield errors remain independent of telescope aperture.

Spectroscopic follow-up is also plagued by atmospheric OH emission and water absorption, which are characterized by many sharp lines and cover the important near-IR region where the optical light of distant supernovae will be redshifted. These discrete features will render any high-precision analysis impossible. The highest redshift supernovae would have to be observed continuously over 150 days to cover its lightcurve, making visibility a serious issue.

Secondary but important disadvantages are worse seeing, the high susceptibility of search efficiency on bad weather, and interference from moonlight.

Adaptive optics for the wide field required for multiplexed follow-up is not foreseeable in the near future and OH-suppressed photometry inherently removes sensitivity at the most important range of wavelength for high-redshift supernova studies.

2.2 What problems are there in searching with other space telescopes that will be available in the next decade?

Observing twenty square degrees with WFPC3 or ACS would require pointings of multiple smaller fields; covering this area of sky *just once* at sufficient depth will require 3-10 years with WFPC3 or ACS, due to their small field size and poor red response. Using the NGST to perform a supernova search with the SNAP specifications is plain overkill as each observation will require 1 minute or 0.05 days for 4500 fields, as compared to the 0.8 days repointing needed to cover the requisite 20 square degrees. Moreover the small field of NGST compromises secondary science goals, such as weak lensing.

2.3 What are the problems with doing follow-up with other space telescopes that will be available in the next decade?

Current experience shows that there is an unavoidable time lag of 1 week between supernova discovery and HST observations. The slow slewing time of the NGST will make it grossly inefficient for photometric follow-up of $z < 2$ supernovae. Using the NGST for spectroscopic confirmation will entail observing spurious candidates since we expect to find ~ 7 times more Type IIs than Type Ias; this would be an inefficient use of NGST time. The NGST will be well suited for late-time spectroscopic follow-up of our highest-redshift candidates.

2.4 Why will a follow-up satellite with a smaller field of view (FOV) coordinated with ground discovery not work?

1) The FOV is not a cost driver. 2) Discovery comes free with SNAP photometry. 3) With discovery on the ground we will lose early discovery. 4) A smaller FOV would decrease the number of SNe that could be followed photometrically. 5) Ground discovery data does not classify the supernovae. Immediate followup data will inefficiently identify the SNe Ia. 6) Ground-based mid-latitude sites would need to look at zenith to minimize detrimental atmospheric effects. In order to access these mid-latitude targets, SNAP, which is currently designed to look at the ecliptic poles, would have to be redesigned to look at a wide range of directions. This would result in the increasing of the zodiacal light background and of thermal design problems.

3 Systematics

3.1 What are the independent checks on gray dust?

Gray dust will re-emit absorbed light and contribute to the far-infrared (FIR) background. Current SCUBA observations indicate that FIR emission from galaxies is close enough to account for all the FIR background without gray dust. Deeper SCUBA and SIRTF measurements should tighten these constraints on the amount of gray dust allowed.

Space-based observations of existing supernovae are now being used to test if gray dust in a non-accelerating universe can be mimicking the effects of an accelerating universe at $z = 0.5$. Results show that the observed color excess is too small to be compatible with the 30% opacity of gray dust needed to be consistent with observations.

3.2 How will gray dust be detected and characterized?

Gray dust at $z < 0.5$ can be directly recognized in SNAP data due to its expected extreme dropoff in absorption above 1.2 μm. Spectroscopic SN Ia and II measurements with extensive wavelength coverage will contain the integrated effect of the dust, and will allow us to measure its absorption as a function of redshift, its clumpiness, and its association with star forming regions. Unless there is an important mechanism that has not been considered in current models of gray dust production at $0.5 < z < 1.8$, lower redshift supernovae will be sufficient to understand the dust. For instance, no gray dust at low redshift will imply no gray dust at high redshift since little destruction of these large grains in the IGM is expected.

3.2.1 and what if there is an important mechanism for dust creation or destruction at $z > 0.5$ that cannot be reconstructed from the dust at $z < 0.5$?

Even with no assumptions on dust evolution, our data will naturally exclude a wide range of gray dust models. Discontinuities in gray dust injection or destruction will produce discontinuities in the derivatives of the measured Hubble law. A wide range of continuous gray dust evolution models, including those currently proposed, are inconsistent with pure cosmological models in the full redshift range that SNAP will observe.

3.3 How degenerate are the combined evolutionary effects?

There are five parameters that together determine the physical state of a given supernova: ^{56}Ni Mass, ^{56}Ni distribution, kinetic energy, opacity, and metallicity. Several of them could, in principle, vary with the evolutionary state of the local host galaxy environment and SN progenitor star. They have a slight degenerate effect on SNAP observables, but should be obtained iteratively using the following sequence:

1. - ^{56}Ni Mass
     Determined by the light curve peak-to-tail ratio.
2. - Opacity
     Determined with the ^{56}Ni mass and lightcurve timescale information ("stretch factor").
   - Metallicity
     Determined from the ^{56}Ni mass and line ratios, UV continuum.
3. - Kinetic Energy
     Determined from metallicity, spectral feature minima, and widths.
   - ^{56}Ni Distribution
     Determined from ^{56}Ni mass, opacity, and the rise time.

Host galaxy properties will also be used as an indicator of the progenitor system.

3.4 How degenerate are gray dust and evolutionary effects?

Fortunately, the key SN Ia physics parameters (e.g. ^{56}Ni Mass, metallicity, opacity) produce evolutionary spectral indicators (e.g. depth, equivalent widths, velocities) and lightcurve indicators (e.g. stretch factor, rise time, plateau level) that will not be affected by the flat absorption of gray dust at optical wavelengths. The expected gray dust signature, an extreme decrease of opacity in the near infrared and flat opacity in the optical, will make evolutionary and dust effects distinguishable.

3.5 Is there evidence for SN Ia evolution?

Signs of "evolution" are already seen in nearby supernovae which explode in galaxies of ages, metallicities, and morphological types that cover the range of environments seen for $z = 0$–1. However, these indicators of diversity are what allow us to correct and homogenize the SN Ia class. Low redshift supernovae from both "young" and "old" galaxy environments are modeled and corrected with no evident systematic residuals. Evolution will have a systematic effect only if the relative populations of progenitor systems varies as a function of redshift in a new way *and* if the models of the Type Ia family are underparametrized.

There is no evidence of evolution beyond that already modeled. For example, the rise times of nearby and distant supernovae are consistent. There is also weak evidence that there is no difference between current high and low-redshift samples. In particular, their magnitude dispersion, color, and "stretch" distributions are consistent.

4 Data

4.1 What are your target peak-magnitude measurement uncertainties?

We designed the satellite to give a supernova corrected peak magnitude uncertainty of ~ 0.1 mag as a baseline, approximately equal to the SN Ia intrinsic magnitude dispersion after correction. The corrections require high-precsion measurements of individual light curve data points, $\Delta m \sim$ 0.03–0.1 mag, in order to produce a final propagated 0.1 peak mag error. The final statistical error for a single supernova will be about 0.15 mag, the quadratic sum of the measurement error and the corrected SN Ia intrinsic magnitude dispersion. Systemtic errors are targeted to be under 0.02 mag.

The expected peak magnitude uncertainties described above are based on corrections derived from ground observations. The unprecedented high-quality SNAP data should provide new and better indicators of supernova brightness, improving the precision with which we can determine a supernova's intrinsic peak brightness to ~ 0.07 mag. This improvement is *not* used for our baseline target uncertainties.

4.2 How do you flatfield in space?

Although further investigation is required, it appears that combining 30 hours of routine SNAP observations will allow the zodiacal background to serve as a flatfield reference. The primary source of difficulty with this strategy is removing faint sources present in the input images but since SNAP is a dedicated mission, baseline flatfields can be obtained prior to launch and updated using smoothed zodiacal light flats. Alternatives include constructing a SNAP flat-field module, or using dithered images of the full moon or the Earth nightglow as sources.

4.3 What will the cosmic-ray rate be in your high-Earth orbit?

The cosmic-ray integrated flux has been measured by Chandra as $2/cm^2/s$ as compared to the HST $1.2/cm^2/s$ rate. This rate will double during the solar minimum, however the solar flare rate will be negligible during this period. A prototype high-resistivity CCD irradiated by 5×10^8 MeV protons has shown no detectable degradation in charge transfer efficiency, down to a factor of 10 lower than that reported for standard CCDs subjected to the same dose.

5 Budget

5.1 Why does SNAP, with its 1 billion pixels, cost less than NGST with 80 million pixels?

SNAP and NGST are not strictly comparable for a number of reasons. The SNAP cost per pixel is entirely reasonable based on modest scaling from existing NASA missions using CCDs. Here are the reasons:

1) Different Detectors: NGST uses HgCdTe. HgCdTe detectors are a more difficult and expensive technology than silicon CCDs. 2) Different Environment: NGST detectors are based in a telescope that runs at 35 degrees Kelvin. This is not a user friendly, low cost environment. 3) The mechanical and space craft environment is also tough in NGST – mirrors have to unfold, and require active control. These demands put additional requirements on the focal plane. 4) A more relevant comparison than NGST is FAME, a funded MidEx mission that contains 200 million pixels. The focal plane for FAME is being built for $\sim$ \$25M. FAME's cost per pixel is reduced by a factor of over 400 from HST CCD systems. In any case, the cost of the CCDs is a very small fraction of the cost of the focal plane instrument.

5.2 What is the main driver of the study/engineering budget?

To do SNAP right will require fairly significant funds to be expended in this early phase. This phase includes not only R&D but also project development – creation of a feasible organization, staffing plan, conceptual designs, cost estimates, schedules, etc. Typical successful projects, where *success* is defined the old fashioned way – delivered within budget, on schedule, with scope intact – require 5%, or more, of the total project cost to be expended in Phase A and initial Phase B (conceptual design). Such a properly and realistically established project will be much easier to complete successfully in the end.

6 Risk

6.1 How will the risks of this space mission be managed?

SNAP members have a proven record in successful space and satellite experiments, and have been responsible for project management, spacecraft, scientific packaging, mission and science operations, and ground station operations. Recent and current satellite missions in which collaboration members have played key roles include the Cosmic Background Explorer, the Extreme Ultra-Violet Explorer, the Fast Auroral Snapshot Explorer, and the High Energy Solar Spectroscopic Imager Spacecraft.

Managing these major space missions involved performing detailed cost, risk, and tradeoff studies, the same type of studies that we will undergo as we enter Phase A of our project. The specifics of issues such as science–cost tradeoffs, risk, the use of new technologies, milestones, and scientific and budgetary oversight will then be tackled.